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**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

In re Patent Application of: Paul A. Farrar  
Title: SELECTIVE DEPOSITION OF SOLDER BALL CONTACTS  
Attorney Docket No.: 303.572US1

**PATENT APPLICATION TRANSMITTAL**

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# SELECTIVE DEPOSITION OF SOLDER BALL CONTACTS

## Technical Field

5 The invention relates generally to forming micro solder balls, and more specifically to forming micro solder balls through selective deposition for bonding integrated circuits to a module substrate or to a circuit board.

## Background Information

10 The central processing units (CPUs) of most modern day computers are typically provided on large circuit boards (mother boards) populated with various integrated circuit (IC) components, such as microprocessors and memory devices. These components contain integrated circuits formed on semiconductor dies, generally for performing a specific function. The components work in conjunction with one another to perform the various functions of the computer. Contacts on the mother board are connected to  
15 contacts on the components by the use of multi-chip modules or directly by conventional means, such as solder. The components are connected to one another by metal patterns formed on the surface of the module, mother board or other support. These metal patterns provide a conduit for data exchange between the components.

20 There is a constant need for computers that operate at faster rates. In order to accommodate this need, various techniques have developed to increase the rate (bandwidth) at which data can be processed and transmitted. One of these involves increasing the circuit complexity of the integrated circuits which also often results in a larger package for the semiconductor die, and an increase in the number of input/output (I/O) terminals required for the semiconductor die. Since the amount of data that can be  
25 accessed from or transferred to a component is directly proportional to the number of I/O lines its semiconductor die contains, increasing the number of I/O terminals directly increases data transfer and processing speed.

Traditionally, semiconductor dies were connected to leads with fine wires (wire bonding). This method of connection was limited by the number of pads which could be

placed on the periphery of the semiconductor die. Considerable progress has been made in reducing the semiconductor die pad size, thereby increasing the number of pads.

However, this technology is still limited by the number of pads which can be formed on the die periphery, and therefore the number of I/Os on a die is likewise limited.

- 5 Therefore, other techniques have been developed over the years to increase the number of available I/O terminals and while accommodating alignment problems.

One of these techniques, known as Controlled Collapse Chip Connection (C4), was developed in the 1960s to deal with the problems associated with alignment of semiconductor dies on a substrate. This process also sought to increase the number of I/O terminals which could be made available for each semiconductor die. The C4 process uses solder bumps deposited on flat contacts on the semiconductor dies to form the bond between the semiconductor die and the leads. The contacts and solder balls on the semiconductor dies are matched with similar flat contacts on the leads to form the connection. Once the die is placed on top of the contacts, the entire device is heated to a temperature which melts the solder. As the solder is allowed to set, a reliable bond is formed between the chip and the leads.

One of the main advantages of this process is that the semiconductor die self-aligns itself on the module substrate based on the high surface tension of the solder. In other words, the chip need not be perfectly aligned over the contacts of the substrate. As long as it is in close proximity, the melting of the solder will align the chip with the substrate contacts. The other advantage of this process is that an increased number of I/O terminals can be fabricated for each semiconductor die as bonding pads are not limited to the periphery of the die. This type of bonding process is also often referred to as "flip-chip" or "micro-bump" bonding. The process can be briefly explained with reference to Figures 1 and 2.

Figure 1 shows a side view of a semiconductor die 10 and a support 20. The semiconductor die 10 is fabricated with various metal pattern lines and contacts 50 imprinted on its last metal level, as shown in Figure 2. Formed beneath the semiconductor die 10 is an array of solder balls 30. The support 20 includes metallized

paths 60 for carrying signals from the semiconductor die 10 to other elements mounted on the support 20. These paths have contacts which match the contacts located on the underside of the semiconductor die 10. When the semiconductor die 10 is ready to be mounted, it is placed on top of the support 20 above the support contacts. The solder balls 30 attached to the contacts of the semiconductor die rest on the contacts of the support, as shown in Figure 1. When the device is heated, the solder melts and the semiconductor die 10 self-aligns with the support contacts. The solder later hardens to form a reliable bond between the two sets of contacts. Figure 3 shows the device after the solder has been heated and set.

Traditionally, the contacts and solder balls have been formed on the semiconductor die using metal mask technology. In this process, a metal mask (essentially a metal plate with a pattern of holes therein) is placed over a substrate containing many semiconductor dies for forming the contacts and solder balls. Then, contact material and solder are evaporated through the holes onto the wafer. The holes in the metal masks must be of sufficient size to prevent warpage and damage of the mask during use. Hence, the number of contacts that can be fabricated through use of a metal mask is limited because the holes in the mask must remain above a minimum size to prevent these problems. Consequently, the size of the solder balls that can be created is similarly limited.

The minimum diameter of a C4 solder ball commonly achieved using current techniques, such as metal mask, is approximately 100 microns. Since the size of the solder balls is directly related to the number and density of I/O terminals that can be fabricated on a given semiconductor die, a decrease in solder ball size would provide for an increase in the number and density of the I/O terminals. This would, in turn, allow for a significant increase in data transmission rates because of the increased number of I/O ports for the packaged IC component.

Hence, there is currently a need for a process for forming solder ball contacts which are less than 100 microns in diameter.

### Summary

The above-mentioned problems with I/O lines on a semiconductor die and other problems are addressed by the invention, and which will be understood by reading and studying the following specification.

5           One embodiment of the invention provides a method for forming solder ball contacts using selective deposition of solder on metal contact pads of a device. The metal contact pads have exposed portions at the bottom of through holes. The through holes define the dimensions of the exposed portions of the metal contact pads, and serve to limit the dimensions of the resulting solder contact by limiting the area upon which  
10       deposition preferentially occurs. Subsequent reflow of the deposited solder contact forms a solder ball contact. Solder ball contacts in accordance with the invention are capable of attaining dimensions of approximately 2.5 microns in diameter.

          In one embodiment, the selective deposition includes immersion contact by immersing the device in molten solder. The molten solder preferentially adheres to the  
15       exposed portions of the metal contact pads upon contact with the pads. Subsequent reflow of the deposited solder forms a solder ball contact.

          In another embodiment, the selective deposition includes chemical vapor deposition of solder. Reactants capable of forming the solder preferentially adhere to the exposed portions of the metal contact pads. The reactants react to form a solder contact  
20       on the exposed portions of the metal contact pads. Subsequent reflow of the deposited solder contact forms a solder ball contact.

          In a further embodiment, the selective deposition includes electrolytic deposition of solder. The solder preferentially forms on the exposed portions of the metal contact pads placed in a cathodic state. Subsequent reflow of the deposited solder forms a solder  
25       ball contact.

          In a still further embodiment, the selective deposition includes electrolytic deposition of solder, where the solder is deposited using more than one layer of material. The layers of deposited material forming the solder preferentially form on the exposed

portions of the metal contact pads placed in a cathodic state. Subsequent reflow of the deposited solder forms a solder ball contact.

Although particularly applicable for use as a replacement for the presently-used processes of forming C4-type connections on semiconductor dies, the same processes of the invention can also be used to form solder ball connections on other supports or substrates.

The above and other advantages and features of the invention will be better understood from the following detailed description of various embodiments of the invention which is provided in connection with the accompanying drawings.

#### Brief Description of the Drawings

Figure 1 is a plan view of an integrated circuit package before C4 bonds are created.

Figure 2 is an elevation view of an integrated circuit package.

Figure 3 is a plan view of an integrated circuit package after the C4 bonds are created.

Figures 4(A)-4(P) are cross-sectional views of an integrated circuit structure in accordance with one embodiment of the invention.

Figures 5(A)-5(C) are cross-sectional views of an integrated circuit structure in accordance with another embodiment of the invention.

Figures 6(A)-6(C) are cross-sectional views of an integrated circuit structure in accordance with still another embodiment of the invention.

Figure 7 is a block diagram of an integrated circuit memory device in accordance with an embodiment of the invention.

Figure 8 is an elevation view of a wafer containing semiconductor dies in accordance with an embodiment of the invention.

Figure 9 is a block diagram of an exemplary circuit module in accordance with an embodiment of the invention.



wafer 110 by a process such as chemical vapor deposition (CVD). The next to last layer of metallurgy 130 includes the metal pattern lines that are coupled to internal circuitry contained on the semiconductor wafer 100. Although CVD silicon dioxide is preferred for the first insulating layer, other insulators (e.g., polyimide, silicon nitride, fluorinated silicon dioxide) known to those skilled in the art may also be used and deposited by conventional techniques. The insulating layer 120 should be applied so that its thickness is at least approximately 2 microns greater than the thickness of the next to last metal layer 130. Then, the structure 100 is planarized using a chemical mechanical polishing process (CMP). The resulting device, after polishing, is as shown in Figure 4(B), where the excess insulating material has been smoothed away.

Next, as shown in Figure 4(C), a first layer of photoresist 125 is deposited over the insulating layer 120. This photoresist layer 125 may be made of any type of photoresist known to those skilled in the art. The photoresist layer 125 is patterned, as shown in Figure 4(D), to define future via holes. The patterned photoresist layer 125 is then used to etch into and remove portions of the insulating layer 120. Figure 4(E) shows the device after the photoresist layer 125 has been exposed, the via holes 140 have been etched, and the photoresist layer 125 has been removed. These via holes 140 provide a connection for upper conductive levels to the next to last layer of metallurgy 130.

Next, solderable metal contact pads 150 are formed on the upper surface of the insulating layer 120. This is accomplished by depositing a second photoresist layer 145 on the planarized insulating layer 120, which will be used as a liftoff layer.

Figure 4(F) shows the device 100 after the photoresist layer 145 has been placed over the insulating layer 120. An insulator such as polyimide may also be used in place of the photoresist layer 145, but it has been found that photoresist provides the best results in the invention. This photoresist layer 145 should be approximately 1.5 microns thick. After it is deposited, the photoresist layer 145 is patterned and etched down to the insulating layer 120 leaving exposed those areas on layer 120 where the metal contact pads 150 are desired, as shown in Figure 4(G). Then, a metal stack preferably containing Zirconium (Zr), Nickel (Ni), Copper (Cu), Gold (Au) and Lead (Pb) is formed overtop of



the entire device 100 including over the remaining areas of photoresist layer 145 and in the etched areas. This stack is formed by applying the five different metals, one at a time, and preferably in the order presented, using methods known in the art. The thicknesses of each layer of metal is preferably approximately 500 Angstroms of Zr, 750 Angstroms of Ni, 5000 Angstroms of Cu, 750 Angstroms of Au and 500 Angstroms of Pb, although these thicknesses are not critical. These metal layers are deposited to form metal stacks 150 in the etched areas of the photoresist layer 145, and to form excess metal stacks 150' on top of the photoresist layer 145. It will be recognized that other metallurgy can be utilized to form metal stacks 150 and 150'.

Since the photoresist layer 145 and the metal layers 150, 150' are applied over the entire surface of the device 100, it is necessary to remove the unwanted metal 150' and photoresist 145 prior to the next process step. Figure 4(H) shows the device 100 after all metal layers have been deposited. The excess metal areas 150' which lie overtop of the photoresist layer 145, must now be removed. This is accomplished by a liftoff process. Liftoff processes are a well known method for removing unwanted portions of a device under fabrication. The present inventor has found that a tape-assisted liftoff process is especially beneficial in the disclosed process. Tape liftoff processes, per se, are known in the art, as evidenced by U.S. patent 5,240,878 to Fitzsimmons, which is incorporated herein by reference. Tape liftoff processes are frequently used to remove unwanted photoresist levels once an imaging and etching has taken place.

The tape utilized is an adhesive-backed polymer (not shown), which is applied overtop of the entire metallized resist layer, so that it contacts metal stacks 150'. The tape bonds to the metal stacks 150', which are, in turn, bonded to the photoresist layer 145. The removal of the tape causes all of the metal stacks 150' and photoresist 145 to be stripped away, leaving metal contact pads 150 in only those areas which were previously etched in the photoresist layer 145. The resulting device 100 after the tape liftoff appears as shown in Figure 4(I).

After the metal contact pads 150 have been formed, a second insulating layer 160 is added overtop of the device 100, as shown in Figure 4(J). This insulating layer 160 can

be formed of conventional insulating material, such as polyimide, and is preferably approximately 1.5 microns thick. Although polyimide is preferred for this layer, any insulator known to those skilled in the art may be used (e.g., silicon dioxide, silicon nitride, fluorinated silicon dioxide).

5           Figure 4(K) shows the next step where a third photoresist layer 170 is deposited. The photoresist layer 170 is preferably approximately 2.5 microns thick. The photoresist layer 170 is exposed and patterned, as shown in Figure 4(L), to define through holes 180 in the areas above the metal contact pads 150. Then, the insulator 160 is etched through the holes 180 so that portions of the metal contact pads 150 are exposed, as shown in  
10   Figure 4(M).

Next, as shown in Figure 4(N), the photoresist layer 170 is removed from device 100. In one embodiment, solder is selectively deposited on the exposed portions of metal contact pads 150, forming solder contacts 200 in the through holes 180, by immersing the device 100 in molten solder. The molten solder will selectively attach to the exposed  
15   metal upon contact, forming solder contacts 200 shown in Figure 4(O).

Solder contacts 200 which connect with metal contact pads 150 project out of the top surface of insulating layer 160. In a further step, the solder contacts 200 may be heated, preferably in a H<sub>2</sub> ambient, to allow them to reflow. When the solder contacts 200 are reflowed they reshape to form solder ball contacts 210, approximating a spherical  
20   shape as shown in Figure 4(P) due to minimization of stress, and the surface tension of the molten solder. The solder may be a lead-tin solder (PbSn), bismuth solders or other solders known in the art.

Another embodiment is also described with reference to Figures 4(A)-4(P). In this embodiment, after the removing the photoresist layer 170 as shown in Figure 4(N),  
25   solder is selectively deposited on the exposed portions of metal contact pads 150, forming solder contacts 200 in the through holes 180. The solder is selectively deposited on device 100 using selective chemical vapor deposition (CVD). CVD utilizes reactive gaseous or vaporized components, i.e., reactants, which combine to form a desired species and, often, a gaseous by-product. The reactants are fed into a reaction chamber

such that the reactants contact a substrate on which deposition is to occur. The mechanism generally involves the reactants being adsorbed on the substrate surface, where they undergo a film-forming chemical reaction thus forming a film on the substrate surface. The film contains the desired species, and by-products are generally removed from a reaction chamber through venting or purging. In this embodiment, the reactants for a metal species should preferentially be adsorbed on the exposed portions of the metal contact pads 150. Subsequent reaction of reactants adsorbed on the exposed portions of the metal contact pads 150 form solder contacts 200 shown in Figure 4(O).

As with the previous embodiment, solder contacts 200 which connect with metal contact pads 150 project out of the top surface of insulating layer 160. In a further step, the solder contacts 200 may be heated, preferably in a  $H_2$  ambient, to allow them to reflow. When the solder contacts 200 are reflowed they reshape to form solder ball contacts 210, approximating a spherical shape as shown in Figure 4(P) due to minimization of stress, and the surface tension of the molten solder.

A further embodiment is described with reference to Figures 4(A)-4(M) and 5(A)-5(C). In this embodiment, processing proceeds to the etching of through holes 180 to metal contact pads 150 as shown in Figure 4(M). Instead of removing the resist at this stage, as in the previous embodiments, solder is applied to the exposed portions of metal contact pads 150 through electrolysis, or electrolytic deposition. Electrolytic deposition generally utilizes a conductive solution of a solvent and an ionically dissociated solute. Through the application of electrical current, metal is deposited at a cathode from a solution containing metal ions. By contacting the exposed portions of the metal contact pads 150 with a conductive solution containing metal ions and placing the metal contact pads 150 in a cathodic state, i.e., making them negative electrodes, solder is selectively deposited on metal contact pads 150 as current is passed through the conductive solution. The deposited solder forms solder contacts 200 as shown in Figure 5(A). Solder contacts 200 are preferably about 2.33 microns deep.

Photoresist layer 170 is then removed, exposing solder contacts 200 above the surface of insulating layer 160 as shown in Figure 5(B). In a further step, the solder

contacts 200 may be heated, preferably in a H<sub>2</sub> ambient, to allow them to reflow. When the solder contacts 200 are reflowed they may reshape to form solder ball contacts 210, approximating a spherical shape similar to those shown in Figure 4(P) due to minimization of stress, and the surface tension of the molten solder. Alternatively, by limiting the annealing conditions, i.e., time and temperature, such that the solder contacts 200 are not fully molten, solder ball contacts 210 may be composite contacts, including both a flat contact portion 215 and a spherical portion 220 in a single unit as shown in Figure 5(C).

A still further embodiment is described with reference to Figures 4(A)-4(M) and 6(A)-6(C). In this embodiment, processing proceeds to the etching of through holes 180 to metal contact pads 150 as shown in Figure 4(M). Instead of removing the resist at this stage, a layer of lead 220 is applied to the exposed portions of metal contact pads 150 through electrolysis. A layer of tin 230 is then formed on the layer of lead 225. The lead layer 225 is preferably approximately 0.91 microns deep. The tin layer 230 is preferably approximately 1.42 microns deep. The lead layer 225 and the tin layer 230 collectively form the solder contacts 200 as shown in Figure 6(A). Other metallurgies may be substituted for the lead/tin combination, and the deposition may include more than two layers.

Photoresist layer 170 is then removed, exposing solder contacts 200 above the surface of insulating layer 160 as shown in Figure 6(B). In a further step, the solder contacts 200 may be heated, preferably in a H<sub>2</sub> ambient, to allow them to reflow. When the solder contacts 200 are reflowed they may reshape to form solder ball contacts 210, approximating a spherical shape similar to those shown in Figure 4(P) due to minimization of stress, and the surface tension of the molten solder. Alternatively, by limiting the annealing conditions, i.e., time and temperature, such that the solder contacts 200 are not fully molten, solder ball contacts 210 may be composite contacts, including both a flat contact portion 215 and a spherical portion 220 in a single unit as shown in Figure 6(C).

Because these solder ball contacts of the invention are formed by selective deposition of solder using fine closely spaced holes, the size of the contacts is decreased significantly. Solder contacts formed in accordance with the invention are capable of attaining dimensions of approximately 2.5 microns in diameter, using a hole of approximately 2 microns in diameter. This is a significant improvement over the prior art solder ball contacts previously described, which are currently on the order of 100 microns in diameter.

Although the invention can be used to form solder ball contacts which are approximately 2.5 microns in diameter, it can also be used by those skilled in the art to produce solder contacts of other sizes, but particularly those in the range of 2.5 microns to 100 microns. For example, it might be desirable to form solder contacts of 10, 25, 50 or 75 microns, or any other size in the range of 2.5 to 100 microns, or in a narrower range such as less than 50 microns, or less than 25 microns, or less than 10 microns, as non-limiting examples.

#### Memory Devices

Figure 7 is a simplified block diagram of a memory device according to one embodiment of the invention. The memory device 300 includes an array of memory cells 302, address decoder 304, row access circuitry 306, column access circuitry 308, control circuitry 310, and Input/Output circuit 312. The memory can be coupled to an external microprocessor 314, or memory controller for memory accessing. The memory receives control signals from the processor 314, such as WE\*, RAS\* and CAS\* signals. The memory is used to store data which is accessed via I/O lines. It will be appreciated by those skilled in the art that additional circuitry and control signals can be provided, and that the memory device of Figure 7 has been simplified to help focus on the invention. Thus, the memory includes internal circuitry, metal pattern lines coupled to the array of memory cells and internal circuitry, and metal contact pads coupled to the metal pattern lines. At least one of the metal contact pads is coupled to a solder ball contact of the invention.

It will be understood that the above description of a DRAM (Dynamic Random Access Memory) is intended to provide a general understanding of the memory and is not a complete description of all the elements and features of a DRAM. Further, the invention is equally applicable to any size and type of memory circuit and is not intended to be limited to the DRAM described above. Other alternative types of devices include SRAM (Static Random Access Memory) or Flash memories. Additionally, the DRAM could be a synchronous DRAM commonly referred to as SGRAM (Synchronous Graphics Random Access Memory), SDRAM (Synchronous Dynamic Random Access Memory), SDRAM II, and DDR SDRAM (Double Data Rate SDRAM), as well as Synchlink or Rambus DRAMs.

As recognized by those skilled in the art, memory devices of the type described herein are generally fabricated as an integrated circuit containing a variety of semiconductor devices. The integrated circuit is supported by a substrate. A substrate is often a silicon wafer, but can additionally refer to silicon-on-insulator (SOI) technology, silicon-on-sapphire (SOS) technology, thin film transistor (TFT) technology and other applicable support structures. The integrated circuits are typically repeated multiple times on each substrate. The substrate is further processed to separate the integrated circuits into dies as is well known in the art.

#### Semiconductor Dies

With reference to Figure 8, in one embodiment, a semiconductor die 710 is produced from a silicon wafer 700. A die is an individual pattern, typically rectangular, on a substrate that contains circuitry, or integrated circuit devices, to perform a specific function. The integrated circuit devices of semiconductor die 710 are coupled to metal pattern lines. The metal pattern lines are coupled to metal contact pads. At least one of the metal contact pads is coupled to a solder ball contact as disclosed herein. A semiconductor wafer will typically contain a repeated pattern of such dies containing the same functionality. Die 710 may contain circuitry for the inventive memory device, as discussed above. Die 710 may further contain additional circuitry to extend to such

complex devices as a monolithic processor with multiple functionality. Die 710 is typically packaged in a protective casing (not shown) with leads extending therefrom (not shown) providing access to the circuitry of the die for unilateral or bilateral communication and control.

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#### Circuit Modules

As shown in Figure 9, two or more dies 710 may be combined, with or without protective casing, into a circuit module 800 to enhance or extend the functionality of an individual die 710. Circuit module 800 may be a combination of dies 710 representing a variety of functions, or a combination of dies 710 containing the same functionality. Some examples of a circuit module include memory modules, device drivers, power modules, communication modems, processor modules and application-specific modules and may include multilayer, multichip modules. Circuit module 800 may be a subcomponent of a variety of electronic systems, such as a clock, a television, a cell phone, a personal computer, an automobile, an industrial control system, an aircraft and others. Circuit module 800 will have a variety of leads 810 extending therefrom and coupled to the dies 710 providing unilateral or bilateral communication and control.

Figure 10 shows one embodiment of a circuit module as memory module 900. Memory module 900 generally depicts a Single Inline Memory Module (SIMM) or Dual Inline Memory Module (DIMM). A SIMM or DIMM is generally a printed circuit board (PCB) or other support containing a series of memory devices. While a SIMM will have a single in-line set of contacts or leads, a DIMM will have a set of leads on each side of the support with each set representing separate I/O signals. Memory module 900 contains multiple memory devices 910 contained on support 915, the number depending upon the desired bus width and the desire for parity. Memory module 900 may contain memory devices 910 on both sides of support 915. Memory module 900 accepts a command signal from an external controller (not shown) on a command link 920 and provides for data input and data output on data links 930. The command link 920 and data links 930

are connected to leads 940 extending from the support 915. Leads 940 are shown for conceptual purposes and are not limited to the positions shown in Figure 10.

### Electronic Systems

5           Figure 11 shows an electronic system 1000 containing one or more circuit modules 800. Electronic system 1000 generally contains a user interface 1010. User interface 1010 provides a user of the electronic system 1000 with some form of control or observation of the results of the electronic system 1000. Some examples of user interface 1010 include the keyboard, pointing device, monitor and printer of a personal computer; 10 the tuning dial, display and speakers of a radio; the ignition switch and gas pedal of an automobile; and the card reader, keypad, display and currency dispenser of an automated teller machine. User interface 1010 may further describe access ports provided to electronic system 1000. Access ports are used to connect an electronic system to the more tangible user interface components previously exemplified. One or more of the 15 circuit modules 800 may be a processor providing some form of manipulation, control or direction of inputs from or outputs to user interface 1010, or of other information either preprogrammed into, or otherwise provided to, electronic system 1000. As will be apparent from the lists of examples previously given, electronic system 1000 will often contain certain mechanical components (not shown) in addition to circuit modules 800 and user interface 1010. It will be appreciated that the one or more circuit modules 800 20 in electronic system 1000 can be replaced by a single integrated circuit. Furthermore, electronic system 1000 may be a subcomponent of a larger electronic system.

          Figure 12 shows one embodiment of an electronic system as memory system 1100. Memory system 1100 contains one or more memory modules 900 and a memory 25 controller 1110. Memory controller 1110 provides and controls a bidirectional interface between memory system 1100 and an external system bus 1120. Memory system 1100 accepts a command signal from the external bus 1120 and relays it to the one or more memory modules 900 on a command link 1130. Memory system 1100 provides for data



input and data output between the one or more memory modules 900 and external system bus 1120 on data links 1140.

Figure 13 shows a further embodiment of an electronic system as a computer system 1200. Computer system 1200 contains a processor 1210 and a memory system 1100 housed in a computer unit 1205. Computer system 1200 is but one example of an electronic system containing another electronic system, i.e., memory system 1100, as a subcomponent. Computer system 1200 optionally contains user interface components. Depicted in Figure 13 are a keyboard 1220, a pointing device 1230, a monitor 1240, a printer 1250 and a bulk storage device 1260. It will be appreciated that other components are often associated with computer system 1200 such as modems, device driver cards, additional storage devices, etc. It will further be appreciated that the processor 1210 and memory system 1100 of computer system 1200 can be incorporated on a single integrated circuit. Such single package processing units reduce the communication time between the processor and the memory circuit.

### Conclusion

Methods of forming solder ball contacts having dimensions of approximately 2.5 microns in diameter have been described. Various devices, modules, systems and other apparatus utilizing the solder ball contacts of the invention have been further described. Apparatus utilizing the solder ball contacts of the invention are capable of increased I/O density over conventional C4 technologies.

While the invention has been described and illustrated with respect to forming solder ball contacts on a semiconductor die, it should be apparent that the same processing techniques can be used to form solder ball contacts on a support, a printed circuit board or other conductor-bearing substrate.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiments shown. Many adaptations of the invention will be apparent to those of ordinary skill in

the art. For example, other methods of producing the metal contact pads and through holes may be used without departing from the scope of the invention. In addition, other metallurgies may be used for the solder or the metal contact pads. Accordingly, this application is intended to cover any adaptations or variations of the invention. It is  
5 manifestly intended that this invention be limited only by the following claims and equivalents thereof.

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What is claimed is:

1. A method of forming a solder ball contact, comprising:  
forming a metal contact pad on a substrate;  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;  
depositing solder on the exposed portion of the metal contact pad using selective deposition, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.
2. The method of claim 1, wherein depositing solder on the exposed portion of the metal contact pad using selective deposition further comprises depositing solder on the exposed portion of the metal contact pad using a deposition process selected from the group consisting of immersion contact, chemical vapor deposition and electrolytic deposition.
3. The method of claim 1, wherein depositing solder further comprises depositing at least one material selected from the group consisting of lead, tin and bismuth.
4. The method of claim 1, wherein forming a metal contact pad further comprises:  
forming a layer of zirconium on the substrate;  
forming a layer of nickel on the layer of zirconium;  
forming a layer of copper on the layer of nickel;  
forming a layer of gold on the layer of copper; and  
forming a layer of lead on the layer of gold.
5. The method of claim 1, wherein forming a metal contact pad further comprises:

forming a layer of zirconium on the substrate, wherein the layer of zirconium is approximately 500 Angstroms thick;  
forming a layer of nickel on the layer of zirconium, wherein the layer of nickel is approximately 750 Angstroms thick;  
forming a layer of copper on the layer of nickel, wherein the layer of copper is approximately 5000 Angstroms thick;  
forming a layer of gold on the layer of copper, wherein the layer of gold is approximately 750 Angstroms thick; and  
forming a layer of lead on the layer of gold, wherein the layer of lead is approximately 500 Angstroms thick.

6. The method of claim 1, wherein annealing the solder contact to form a solder ball contact comprises a solder ball contact approximating a spherical shape.
7. The method of claim 1, wherein annealing the solder contact to form a solder ball contact comprises a solder ball contact having a spherical portion and a flat contact portion.
8. The method of claim 1, wherein removing a portion of the insulating layer further comprises forming an exposed portion of the metal contact pad having a diameter of approximately 2 microns.
9. A method of forming a solder ball contact, comprising:  
forming a metal contact pad on a substrate;  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;  
immersing the substrate in molten solder;

depositing solder on the exposed portion of the metal contact pad, thereby  
forming a solder contact; and  
annealing the solder contact to form a solder ball contact.

10. The method of claim 9, wherein immersing the substrate in molten solder comprises immersing the substrate in molten solder having at least one material selected from the group consisting of lead, tin and bismuth.
11. A method of forming a solder ball contact, comprising:  
forming a metal contact pad on a substrate;  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad, wherein the exposed portion of the metal contact pad has a diameter of approximately 2 microns;  
immersing the substrate in molten lead;  
depositing lead on the exposed portion of the metal contact pad, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.
12. A method of forming a solder ball contact, comprising:  
forming a metal contact pad on a substrate;  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;  
adsorbing reactants on the exposed portion of the metal contact pad;  
reacting the reactants on the exposed portion of the metal contact pad, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.

13. A method of forming a solder ball contact, comprising:
  - forming a metal contact pad on a substrate;
  - forming an insulating layer on the metal contact pad;
  - forming a resist layer on the insulating layer;
  - patterning the resist layer to define a future exposed portion of the metal contact pad;
  - removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming the exposed portion of the metal contact pad;
  - electrolytically depositing solder on the exposed portion of the metal contact pad, thereby forming a solder contact;
  - removing the resist layer, thereby exposing the solder contact above a surface of the insulating layer; and
  - annealing the solder contact to form a solder ball contact.
14. The method of claim 13, wherein electrolytically depositing solder on the exposed portion of the metal contact pad comprises electrolytically depositing at least one material selected from the group consisting of lead, tin and bismuth.
15. A method of forming a solder ball contact, comprising:
  - forming a metal contact pad on a substrate;
  - forming an insulating layer on the metal contact pad, wherein the insulating layer has a thickness of approximately 1.5 microns;
  - forming a resist layer on the insulating layer;
  - patterning the resist layer to define a future exposed portion of the metal contact pad;
  - removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming the exposed portion of the metal contact pad,

wherein the exposed portion of the metal contact pad has a diameter of approximately 2 microns;  
 electrolytically depositing lead on the exposed portion of the metal contact pad, thereby forming a solder contact, wherein the solder contact has a thickness of approximately 2.33 microns;  
 removing the resist layer, thereby exposing the solder contact above a surface of the insulating layer; and  
 annealing the solder contact to form a solder ball contact.

16. A method of forming a solder ball contact, comprising:  
 forming a metal contact pad on a substrate;  
 forming an insulating layer on the metal contact pad;  
 forming a resist layer on the insulating layer;  
 patterning the resist layer to define a future exposed portion of the metal contact pad;  
 removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming the exposed portion of the metal contact pad;  
 electrolytically depositing a first metal layer on the exposed portion of the metal contact pad;  
 electrolytically depositing a second metal layer on the first metal layer, wherein the first metal layer and the second metal layer form a solder contact;  
 removing the resist layer, thereby exposing the solder contact above a surface of the insulating layer; and  
 annealing the solder contact to form a solder ball contact.
17. The method of claim 16, wherein electrolytically depositing a first metal layer comprises electrolytically depositing a first metal layer containing at least one material selected from the group consisting of lead, tin and bismuth.

18. The method of claim 16, wherein electrolytically depositing a second metal layer comprises electrolytically depositing a second metal layer containing at least one material selected from the group consisting of lead, tin and bismuth.
19. The method of claim 16, wherein electrolytically depositing a first metal layer comprises electrolytically depositing a layer of lead and wherein electrolytically depositing a second metal layer comprises electrolytically depositing a layer of tin.
20. The method of claim 19, wherein electrolytically depositing a layer of lead comprises electrolytically depositing a layer of lead to a thickness of approximately 0.91 microns and wherein electrolytically depositing a layer of tin comprises electrolytically depositing a layer of tin to a thickness of approximately 1.42 microns.
21. The method of claim 16, wherein annealing the solder contact to form a solder ball contact comprises a solder ball contact approximating a spherical shape.
22. The method of claim 16, wherein annealing the solder contact to form a solder ball contact comprises a solder ball contact having a spherical portion and a flat contact portion.
23. A method of forming a solder ball contact, comprising:
  - forming a metal contact pad on a substrate;
  - forming an insulating layer on the metal contact pad, wherein the insulating layer has a thickness of approximately 1.5 microns;
  - forming a resist layer on the insulating layer;
  - patterning the resist layer to define a future exposed portion of the metal contact pad;



removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming the exposed portion of the metal contact pad, wherein the exposed portion of the metal contact pad has a diameter of approximately 2 microns;

electrolytically depositing a layer of lead on the exposed portion of the metal contact pad, wherein the layer of lead has a thickness of approximately 0.91 microns;

electrolytically depositing a layer of tin on the layer of lead, wherein the layer of tin has a thickness of approximately 1.42 microns, further wherein the layer of lead and the layer of tin form a solder contact having a thickness of approximately 2.33 microns;

removing the resist layer, thereby exposing the solder contact above a surface of the insulating layer; and

annealing the solder contact to form a solder ball contact.

24. A semiconductor die, comprising:
- an integrated circuit supported by a substrate;
  - a metal pattern line coupled to the integrated circuit;
  - a metal contact pad coupled to the metal pattern line; and
  - a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:
    - forming an insulating layer on the metal contact pad;
    - removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;
    - depositing solder on the exposed portion of the metal contact pad using selective deposition, thereby forming a solder contact; and
    - annealing the solder contact to form a solder ball contact.

25. The semiconductor die of claim 24, wherein the solder ball contact is formed by a method, the method further comprising depositing solder on the exposed portion of the metal contact pad using a deposition process selected from the group consisting of immersion contact, chemical vapor deposition and electrolytic deposition.
26. The semiconductor die of claim 24, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
27. A semiconductor die, comprising:  
an integrated circuit supported by a substrate;  
a metal pattern line coupled to the integrated circuit;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;  
immersing the substrate in molten solder;  
depositing solder on the exposed portion of the metal contact pad, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.
28. The semiconductor die of claim 27, wherein the molten solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
29. A semiconductor die, comprising:  
an integrated circuit supported by a substrate;

a metal pattern line coupled to the integrated circuit;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;  
adsorbing reactants on the exposed portion of the metal contact pad;  
reacting the reactants on the exposed portion of the metal contact pad, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.

30. A semiconductor die, comprising:  
an integrated circuit supported by a substrate;  
a metal pattern line coupled to the integrated circuit;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
forming a resist layer on the insulating layer;  
patterning the resist layer to define a future exposed portion of the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming the exposed portion of the metal contact pad;  
electrolytically depositing solder on the exposed portion of the metal contact pad, thereby forming a solder contact;

removing the resist layer, thereby exposing the solder contact  
above a surface of the insulating layer; and  
annealing the solder contact to form a solder ball contact.

31. The semiconductor die of claim 30, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
32. A memory device, comprising:  
an array of memory cells;  
a metal pattern line coupled to the array of memory cells;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;  
depositing solder on the exposed portion of the metal contact pad using selective deposition, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.
33. The memory device of claim 32, wherein the solder ball contact is formed by a method, the method further comprising depositing solder on the exposed portion of the metal contact pad using a deposition process selected from the group consisting of immersion contact, chemical vapor deposition and electrolytic deposition.

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34. The memory device of claim 32, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
35. A memory device, comprising:  
an array of memory cells;  
a metal pattern line coupled to the array of memory cells;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;  
immersing the substrate in molten solder;  
depositing solder on the exposed portion of the metal contact pad, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.
36. The memory device of claim 35, wherein the molten solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
37. A memory device, comprising:  
an array of memory cells;  
a metal pattern line coupled to the array of memory cells;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;

removing a portion of the insulating layer to expose a portion of  
the metal contact pad, thereby forming an exposed portion  
of the metal contact pad;  
adsorbing reactants on the exposed portion of the metal contact  
pad;  
reacting the reactants on the exposed portion of the metal contact  
pad, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.

38. A memory device, comprising:  
an array of memory cells;  
a metal pattern line coupled to the array of memory cells;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball  
contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
forming a resist layer on the insulating layer;  
patterning the resist layer to define a future exposed portion of the  
metal contact pad;  
removing a portion of the insulating layer to expose a portion of  
the metal contact pad, thereby forming the exposed portion  
of the metal contact pad;  
electrolytically depositing solder on the exposed portion of the  
metal contact pad, thereby forming a solder contact;  
removing the resist layer, thereby exposing the solder contact  
above a surface of the insulating layer; and  
annealing the solder contact to form a solder ball contact.

39. The memory device of claim 38, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
40. A memory module, comprising:  
a support;  
a plurality of leads extending from the support;  
a command link coupled to at least one of the plurality of leads;  
a plurality of data links, wherein each data link is coupled to at least one of the plurality of leads; and  
at least one memory device contained on the support and coupled to the command link, wherein the at least one memory device comprises:  
an array of memory cells;  
a metal pattern line coupled to the array of memory cells;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;  
depositing solder on the exposed portion of the metal contact pad using selective deposition, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.

41. The memory module of claim 40, wherein the solder ball contact is formed by a method, the method further comprising depositing solder on the exposed portion of the metal contact pad using a deposition process selected from the group consisting of immersion contact, chemical vapor deposition and electrolytic deposition.
42. The memory module of claim 40, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
43. A memory module, comprising:
  - a support;
  - a plurality of leads extending from the support;
  - a command link coupled to at least one of the plurality of leads;
  - a plurality of data links, wherein each data link is coupled to at least one of the plurality of leads; and
  - at least one memory device contained on the support and coupled to the command link, wherein the at least one memory device comprises:
    - an array of memory cells;
    - a metal pattern line coupled to the array of memory cells;
    - a metal contact pad coupled to the metal pattern line; and
    - a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:
      - forming an insulating layer on the metal contact pad;
      - removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;
      - immersing the substrate in molten solder;



depositing solder on the exposed portion of the  
metal contact pad, thereby forming a solder  
contact; and  
annealing the solder contact to form a solder ball  
contact.

44. The memory module of claim 43, wherein the molten solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
45. A memory module, comprising:  
a support;  
a plurality of leads extending from the support;  
a command link coupled to at least one of the plurality of leads;  
a plurality of data links, wherein each data link is coupled to at least one of the plurality of leads; and  
at least one memory device contained on the support and coupled to the command link, wherein the at least one memory device comprises:  
an array of memory cells;  
a metal pattern line coupled to the array of memory cells;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming an exposed portion of the metal contact pad;

adsorbing reactants on the exposed portion of the  
metal contact pad;  
reacting the reactants on the exposed portion of the  
metal contact pad, thereby forming a solder  
contact; and  
annealing the solder contact to form a solder ball  
contact.

46. A memory module, comprising:
- a support;
  - a plurality of leads extending from the support;
  - a command link coupled to at least one of the plurality of leads;
  - a plurality of data links, wherein each data link is coupled to at least one of the plurality of leads; and
  - at least one memory device contained on the support and coupled to the command link, wherein the at least one memory device comprises:
    - an array of memory cells;
    - a metal pattern line coupled to the array of memory cells;
    - a metal contact pad coupled to the metal pattern line; and
    - a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:
      - forming an insulating layer on the metal contact pad;
      - forming a resist layer on the insulating layer;
      - patterning the resist layer to define a future exposed portion of the metal contact pad;
      - removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby

forming the exposed portion of the metal contact pad;  
electrolytically depositing solder on the exposed portion of the metal contact pad, thereby forming a solder contact;  
removing the resist layer, thereby exposing the solder contact above a surface of the insulating layer; and  
annealing the solder contact to form a solder ball contact.

47. The memory module of claim 46, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
48. A memory system, comprising:  
a controller;  
a command link coupled to the controller;  
a data link coupled to the controller; and  
a memory device coupled to the command link and the data link, wherein the memory device comprises:  
an array of memory cells;  
a metal pattern line coupled to the array of memory cells;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby

General information		Study design		Study population		Intervention		Outcome	
Variable	Value	Variable	Value	Variable	Value	Variable	Value	Variable	Value
Study ID	123456	Study type	Randomized controlled trial	Study location	University Hospital	Intervention group	Group A	Outcome measure	Mean difference
Study title	Effect of intervention on outcome	Study year	2020	Study duration	12 weeks	Control group	Group B	Primary outcome	95% CI
Study authors	Smith et al.	Study funding	Government grant	Study sample size	100	Intervention details	Group A	Secondary outcome	P-value
Study objectives	To evaluate the effect of intervention on outcome	Study hypothesis	Intervention will improve outcome	Study inclusion criteria	Adults > 18 years	Control details	Group B	Statistical significance	Yes/No
Study methods	Randomized controlled trial	Study results	Intervention group showed better outcome	Study exclusion criteria	Patients with comorbidities	Intervention results	Group A	Conclusion	Intervention is effective
Study limitations	Small sample size	Study strengths	High internal validity	Study follow-up	12 weeks	Control results	Group B	Recommendations	Further research needed
Study conclusions	Intervention is effective	Study references	See references	Study funding source	Government grant	Intervention cost	Group A	Study limitations	Small sample size
Study funding	Government grant	Study ethics approval	Yes	Study registration	Yes	Control cost	Group B	Study strengths	High internal validity
Study ethics approval	Yes	Study registration	Yes	Study publication	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Control cost	Group B	Study strengths	High internal validity
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Control cost	Group B	Study strengths	High internal validity
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Intervention cost	Group A	Study limitations	Small sample size
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Control cost	Group B	Study strengths	High internal validity
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Control cost	Group B	Study strengths	High internal validity
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Control cost	Group B	Study strengths	High internal validity
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Intervention cost	Group A	Study limitations	Small sample size
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Control cost	Group B	Study strengths	High internal validity
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Control cost	Group B	Study strengths	High internal validity
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Control cost	Group B	Study strengths	High internal validity
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Intervention cost	Group A	Study limitations	Small sample size
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Control cost	Group B	Study strengths	High internal validity
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Control cost	Group B	Study strengths	High internal validity
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Control cost	Group B	Study strengths	High internal validity
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Intervention cost	Group A	Study limitations	Small sample size
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Control cost	Group B	Study strengths	High internal validity
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Control cost	Group B	Study strengths	High internal validity
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Control cost	Group B	Study strengths	High internal validity
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Intervention cost	Group A	Study limitations	Small sample size
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Control cost	Group B	Study strengths	High internal validity
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Control cost	Group B	Study strengths	High internal validity
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Intervention cost	Group A	Study limitations	Small sample size
Study funding source	Government grant	Study registration	Yes	Study publication	Yes	Control cost	Group B	Study strengths	High internal validity
Study registration	Yes	Study publication	Yes	Study funding source	Government grant	Intervention cost	Group A	Study limitations	Small sample size
Study publication	Yes	Study funding source	Government grant	Study registration	Yes	Control cost	Group B	Study strengths	High internal validity
Study funding source	Government grant	Study registration	Yes	Study					

- | General information       |                                                   | Study design      |                                       | Study population         |                             | Intervention           |         | Outcome                  |                           |
|---------------------------|---------------------------------------------------|-------------------|---------------------------------------|--------------------------|-----------------------------|------------------------|---------|--------------------------|---------------------------|
| Variable                  | Value                                             | Variable          | Value                                 | Variable                 | Value                       | Variable               | Value   | Variable                 | Value                     |
| Study ID                  | 123456                                            | Study type        | Randomized controlled trial           | Study location           | University Hospital         | Intervention group     | Group A | Outcome measure          | Mean difference           |
| Study title               | Effect of intervention on outcome                 | Study year        | 2020                                  | Study duration           | 12 weeks                    | Control group          | Group B | Primary outcome          | 95% CI                    |
| Study authors             | Smith et al.                                      | Study funding     | Government grant                      | Study sample size        | 100                         | Intervention details   | Group A | Secondary outcome        | P-value                   |
| Study objectives          | To evaluate the effect of intervention on outcome | Study hypothesis  | Intervention will improve outcome     | Study inclusion criteria | Adults with condition       | Intervention duration  | Group A | Adverse events           | Number of events          |
| Study methods             | Randomized controlled trial                       | Study results     | Intervention group showed improvement | Study exclusion criteria | Children and pregnant women | Intervention frequency | Group A | Statistical significance | Yes/No                    |
| Study findings            | Intervention was effective                        | Study conclusions | Intervention should be used           | Study limitations        | Small sample size           | Intervention intensity | Group A | Generalizability         | High/Low                  |
| Study recommendations     | Further research needed                           | Study references  | See references                        | Study strengths          | Randomized design           | Intervention timing    | Group A | Cost-effectiveness       | Yes/No                    |
| Study contact information | See contact information                           | Study keywords    | Intervention, outcome                 | Study funding sources    | Government grant            | Intervention setting   | Group A | Conclusion               | Intervention is effective |

removing a portion of the insulating layer to expose  
a portion of the metal contact pad, thereby  
forming an exposed portion of the metal  
contact pad;  
immersing the substrate in molten solder;  
depositing solder on the exposed portion of the  
metal contact pad, thereby forming a solder  
contact; and  
annealing the solder contact to form a solder ball  
contact.

52. The memory system of claim 51, wherein the molten solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
53. A memory system, comprising:  
a controller;  
a command link coupled to the controller;  
a data link coupled to the controller; and  
a memory device coupled to the command link and the data link, wherein the memory device comprises:  
an array of memory cells;  
a metal pattern line coupled to the array of memory cells;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose  
a portion of the metal contact pad, thereby

forming an exposed portion of the metal contact pad;  
adsorbing reactants on the exposed portion of the metal contact pad;  
reacting the reactants on the exposed portion of the metal contact pad, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.

54. A memory system, comprising:
- a controller;
  - a command link coupled to the controller;
  - a data link coupled to the controller; and
  - a memory device coupled to the command link and the data link, wherein the memory device comprises:
    - an array of memory cells;
    - a metal pattern line coupled to the array of memory cells;
    - a metal contact pad coupled to the metal pattern line; and
    - a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:
      - forming an insulating layer on the metal contact pad;
      - forming a resist layer on the insulating layer;
      - patterning the resist layer to define a future exposed portion of the metal contact pad;
      - removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby

forming the exposed portion of the metal contact pad;  
electrolytically depositing solder on the exposed portion of the metal contact pad, thereby forming a solder contact;  
removing the resist layer, thereby exposing the solder contact above a surface of the insulating layer; and  
annealing the solder contact to form a solder ball contact.

55. The memory system of claim 54, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
56. An electronic system, comprising:  
a processor; and  
a circuit module having a plurality of leads coupled to the processor, and further having a semiconductor die coupled to the plurality of leads, wherein the semiconductor die comprises:  
an integrated circuit supported by a substrate;  
a metal pattern line coupled to the integrated circuit;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby

forming an exposed portion of the metal contact pad;  
depositing solder on the exposed portion of the metal contact pad using selective deposition, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.

57. The electronic system of claim 56, wherein the solder ball contact is formed by a method, the method further comprising depositing solder on the exposed portion of the metal contact pad using a deposition process selected from the group consisting of immersion contact, chemical vapor deposition and electrolytic deposition.

58. The electronic system of claim 56, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.

59. An electronic system, comprising:  
a processor; and  
a circuit module having a plurality of leads coupled to the processor, and further having a semiconductor die coupled to the plurality of leads, wherein the semiconductor die comprises:

an integrated circuit supported by a substrate;  
a metal pattern line coupled to the integrated circuit;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;



removing a portion of the insulating layer to expose  
a portion of the metal contact pad, thereby  
forming an exposed portion of the metal  
contact pad;  
immersing the substrate in molten solder;  
depositing solder on the exposed portion of the  
metal contact pad, thereby forming a solder  
contact; and  
annealing the solder contact to form a solder ball  
contact.

60. The electronic system of claim 59, wherein the molten solder comprises at least one material selected from the group consisting of lead, tin and bismuth.
61. An electronic system, comprising:  
a processor; and  
a circuit module having a plurality of leads coupled to the processor, and further having a semiconductor die coupled to the plurality of leads, wherein the semiconductor die comprises:  
an integrated circuit supported by a substrate;  
a metal pattern line coupled to the integrated circuit;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
removing a portion of the insulating layer to expose  
a portion of the metal contact pad, thereby

forming an exposed portion of the metal contact pad;  
adsorbing reactants on the exposed portion of the metal contact pad;  
reacting the reactants on the exposed portion of the metal contact pad, thereby forming a solder contact; and  
annealing the solder contact to form a solder ball contact.

62. An electronic system, comprising:  
a processor; and  
a circuit module having a plurality of leads coupled to the processor, and further having a semiconductor die coupled to the plurality of leads, wherein the semiconductor die comprises:  
an integrated circuit supported by a substrate;  
a metal pattern line coupled to the integrated circuit;  
a metal contact pad coupled to the metal pattern line; and  
a solder ball contact coupled to the metal contact pad, wherein the solder ball contact is formed by a method comprising:  
forming an insulating layer on the metal contact pad;  
forming a resist layer on the insulating layer;  
patterning the resist layer to define a future exposed portion of the metal contact pad;  
removing a portion of the insulating layer to expose a portion of the metal contact pad, thereby forming the exposed portion of the metal contact pad;

electrolytically depositing solder on the exposed  
portion of the metal contact pad, thereby  
forming a solder contact;  
removing the resist layer, thereby exposing the  
solder contact above a surface of the  
insulating layer; and  
annealing the solder contact to form a solder ball  
contact.

63. The electronic system of claim 62, wherein the solder comprises at least one material selected from the group consisting of lead, tin and bismuth.

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Abstract of the Disclosure

Methods of forming solder ball contacts having dimensions of approximately 2.5 microns in diameter for use in C4-type connections. The methods form solder ball contacts using selective deposition of solder on metal contact pads of a device. The metal contact pads have exposed portions at the bottom of through holes. The through holes define the dimensions of the exposed portions of the metal contact pads, and serve to limit the dimensions of the resulting solder contact by limiting the area upon which deposition preferentially occurs. Subsequent reflow of the deposited solder forms a solder ball contact. Various devices, modules, systems and other apparatus utilizing such methods of forming solder ball contacts.

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Date of Deposit: February 19, 1999

I hereby certify that this paper or fee is being deposited with the United States Postal Service as "Express Mail Post Office to Addressee" service under 37 CFR §1.10 on the date indicated above and in an envelope addressed to Assistant Commissioner for Patents, Washington, D.C. 20231.

Chris Hammond

(Name)

Chris Hammond

(Signature)

February 19, 1999

(Date)

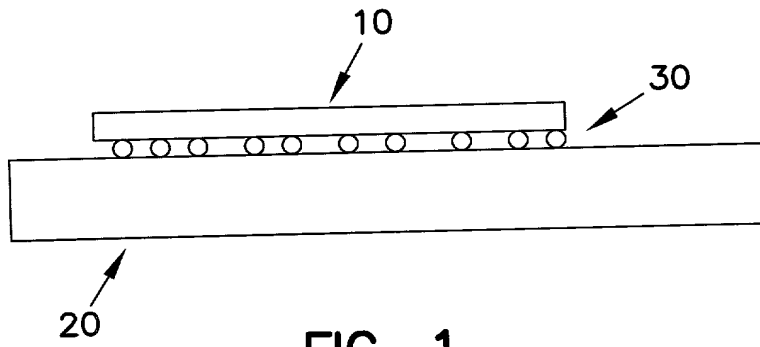


FIG. 1

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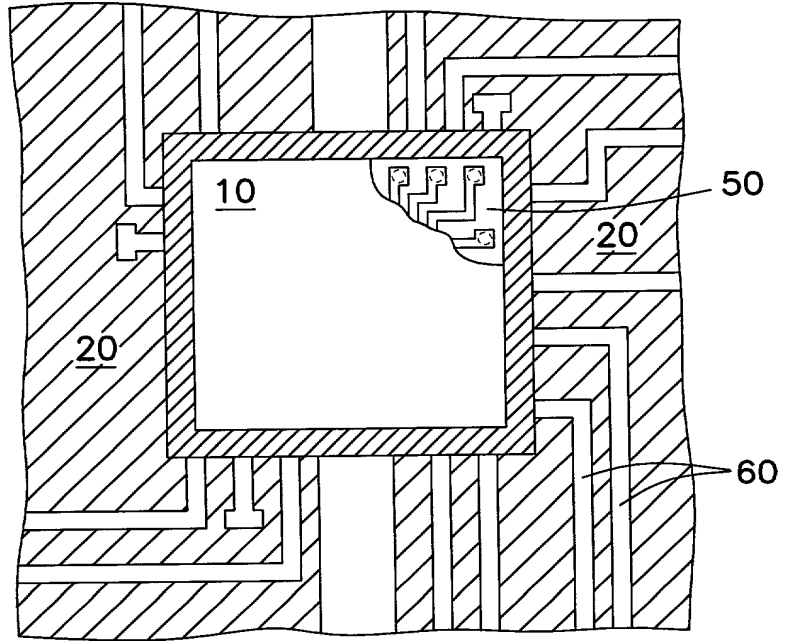


FIG. 2

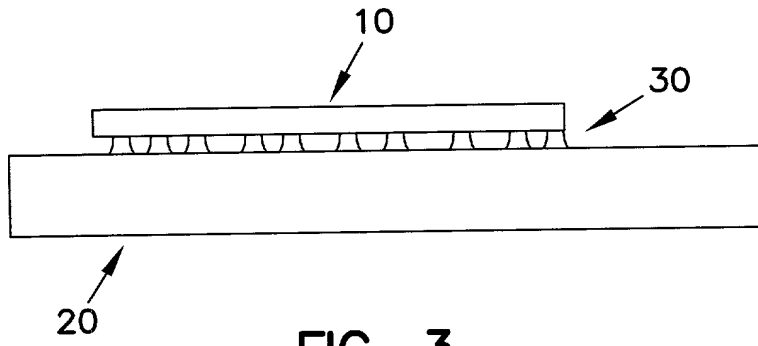


FIG. 3

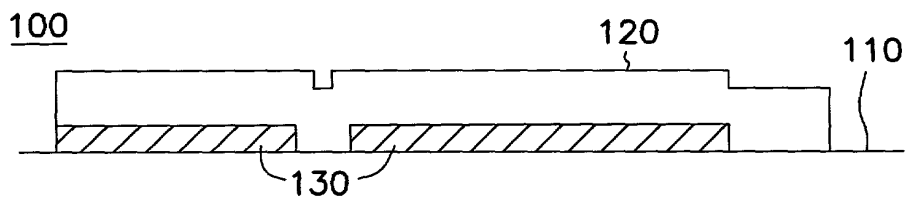


FIG. 4(A)

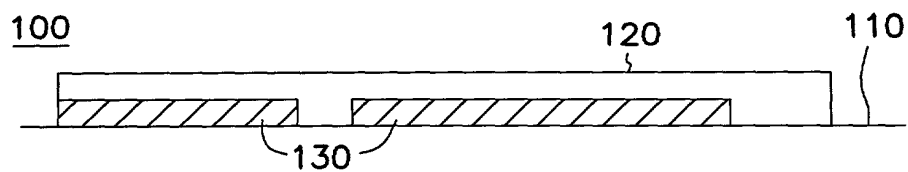


FIG. 4(B)

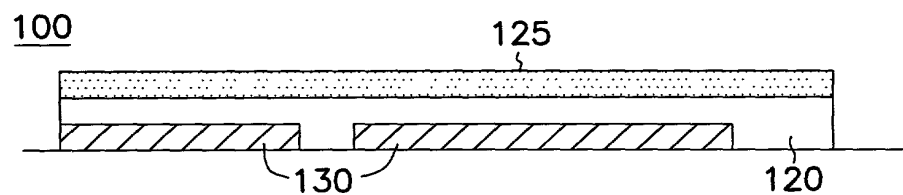


FIG. 4(C)

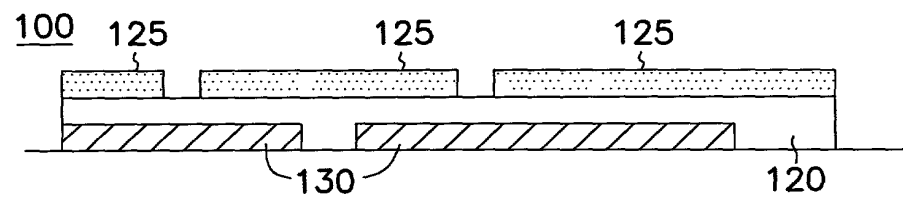


FIG. 4(D)

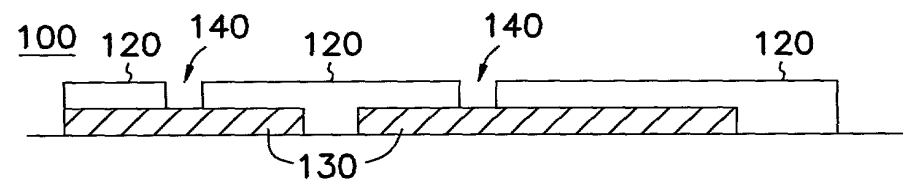


FIG. 4(E)



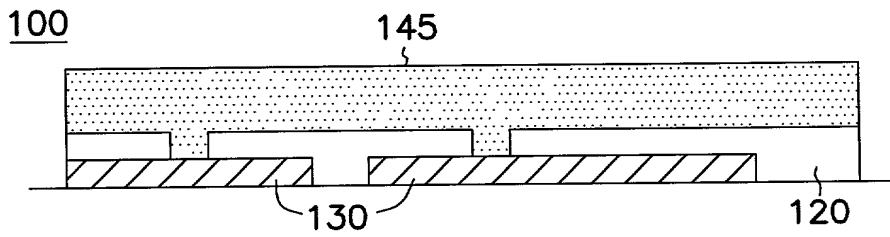


FIG. 4(F)

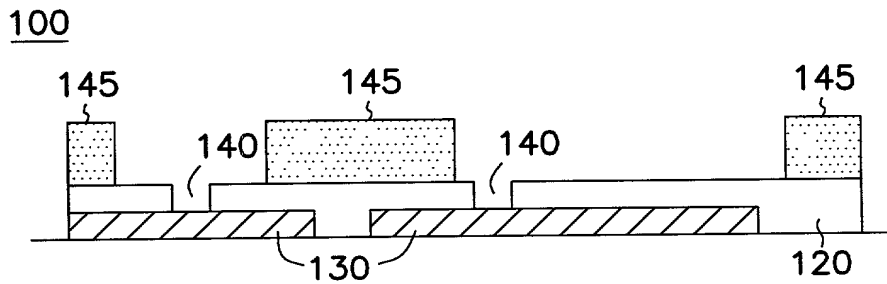


FIG. 4(G)

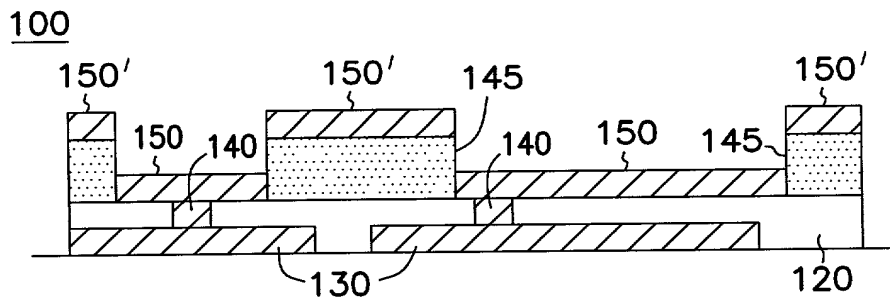


FIG. 4(H)

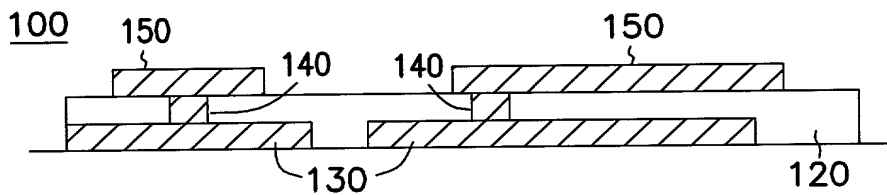


FIG. 4(I)

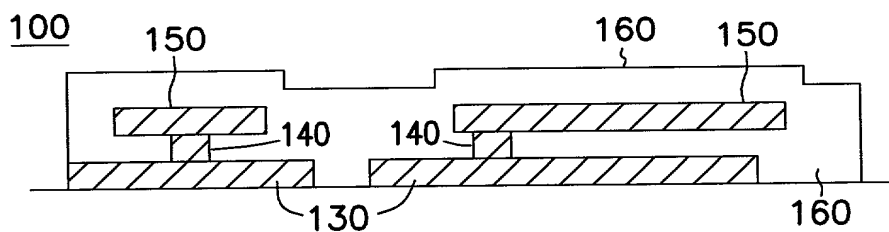


FIG. 4(J)

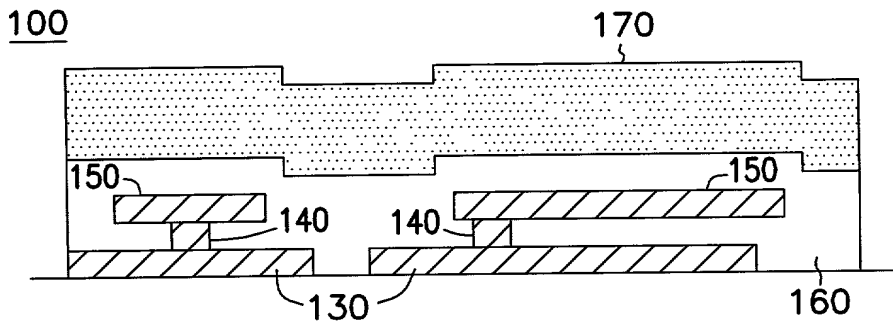


FIG. 4(K)

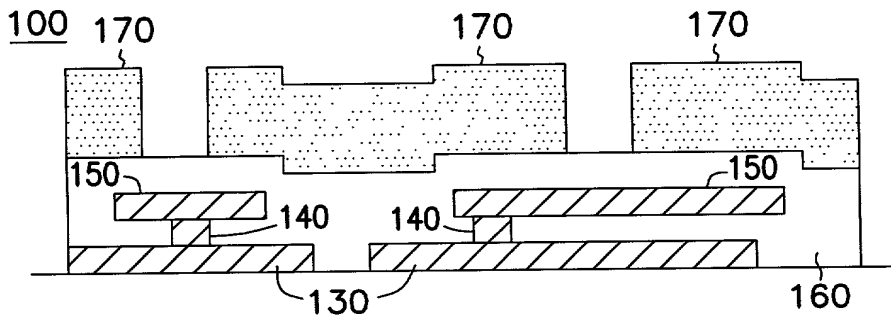


FIG. 4(L)

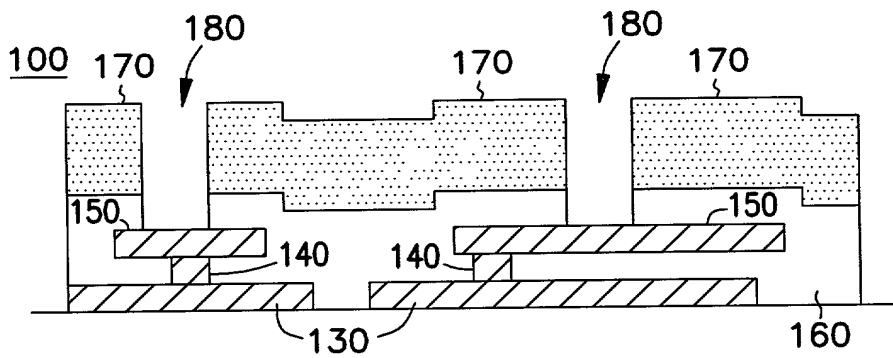


FIG. 4(M)

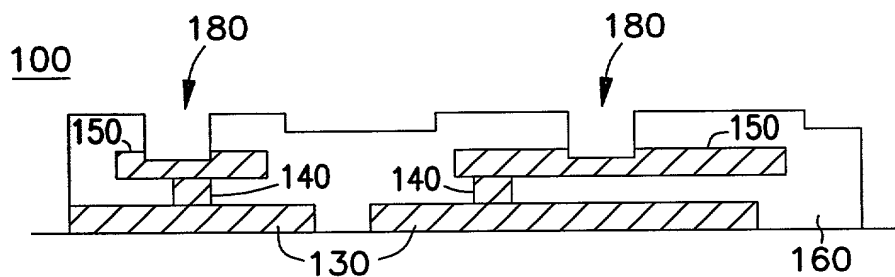


FIG. 4(N)

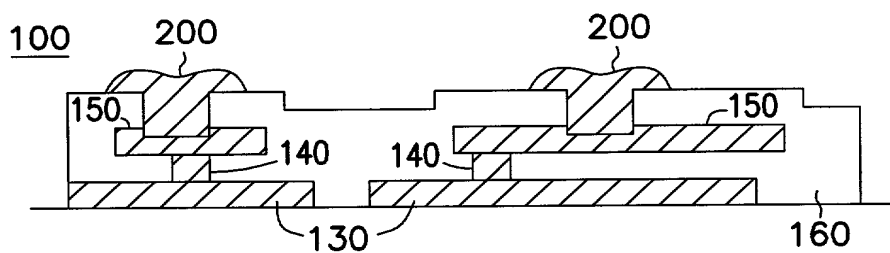


FIG. 4(O)

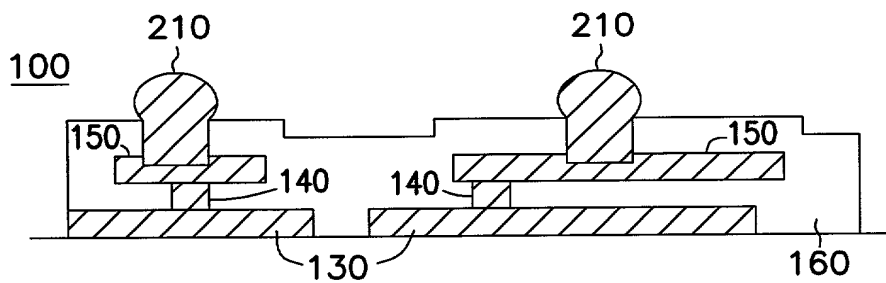


FIG. 4(P)

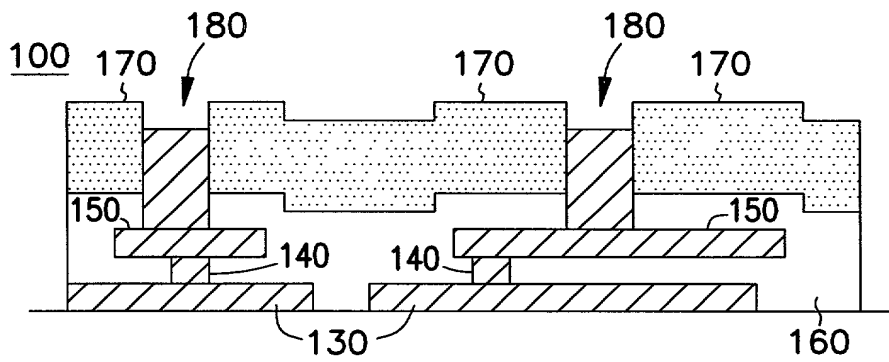


FIG. 5(A)

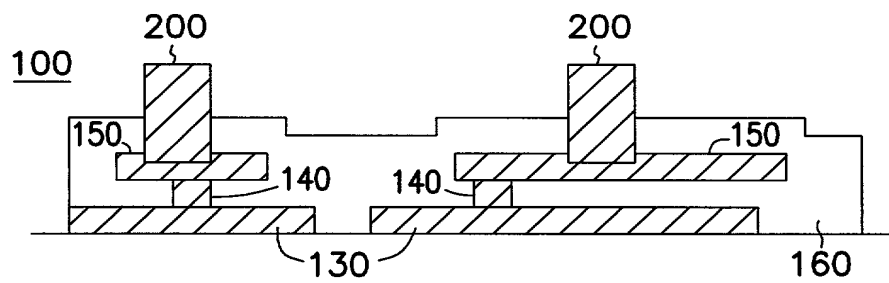


FIG. 5(B)

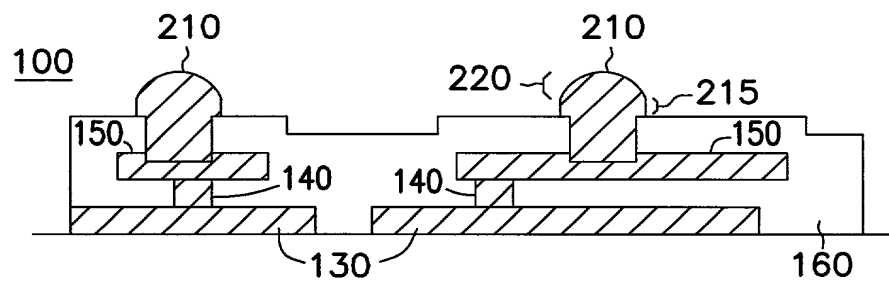


FIG. 5(C)

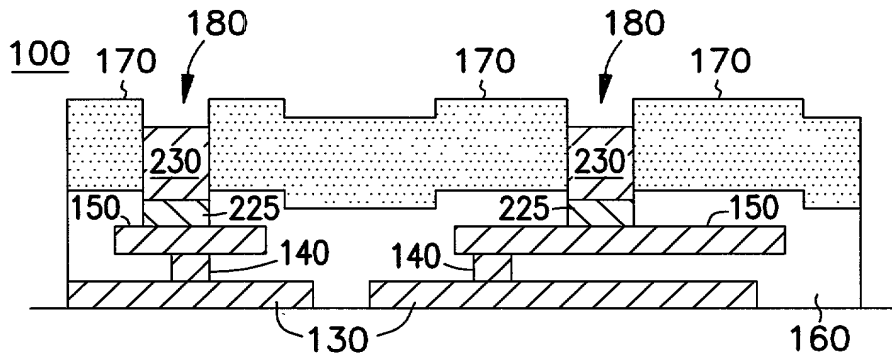


FIG. 6(A)

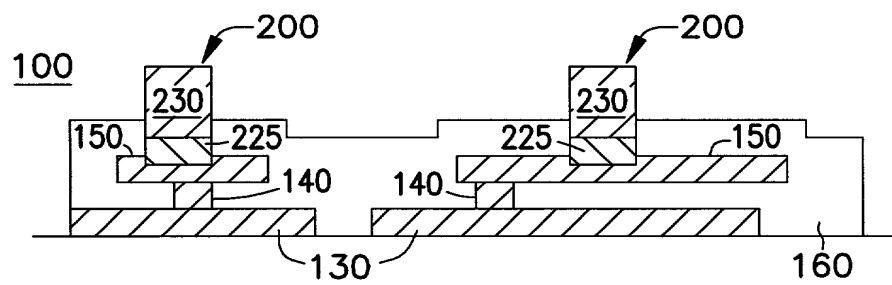


FIG. 6(B)

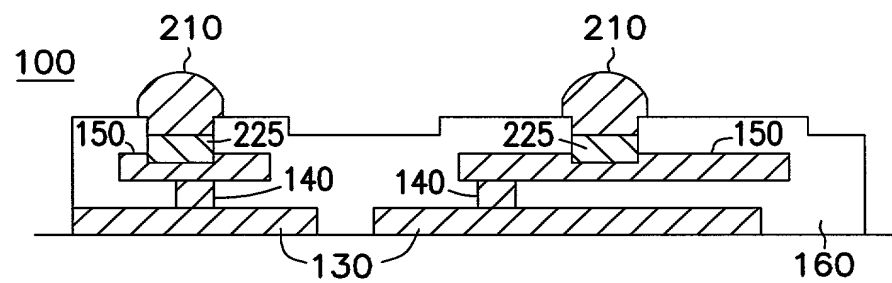


FIG. 6(C)

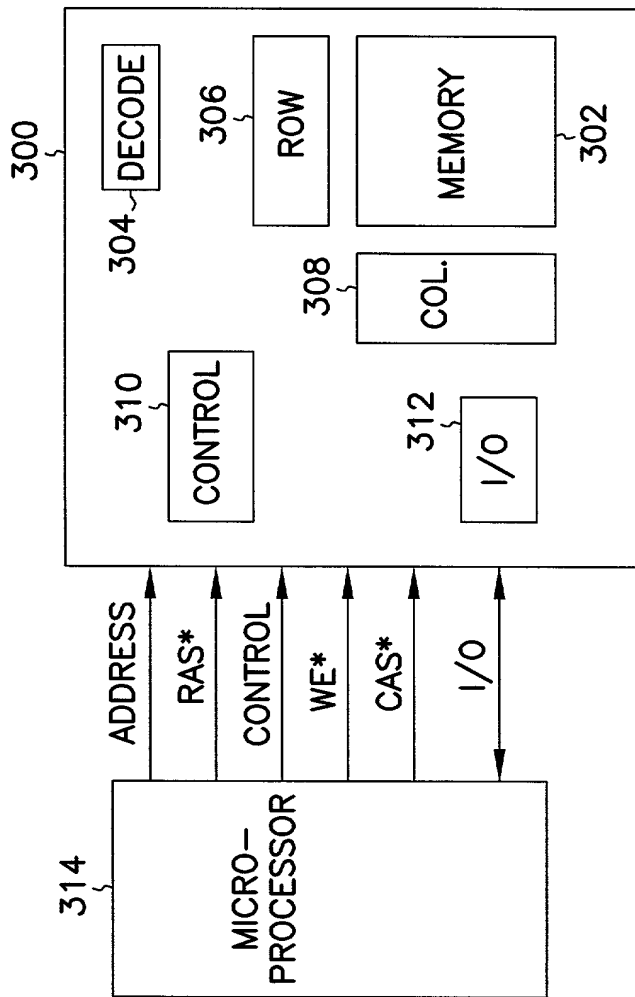


FIG. 7

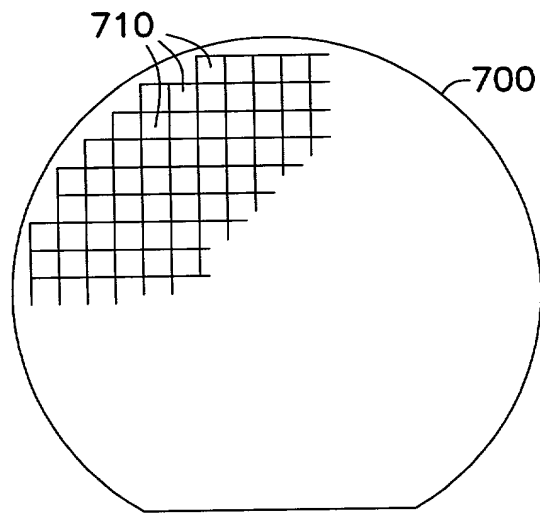


FIG. 8

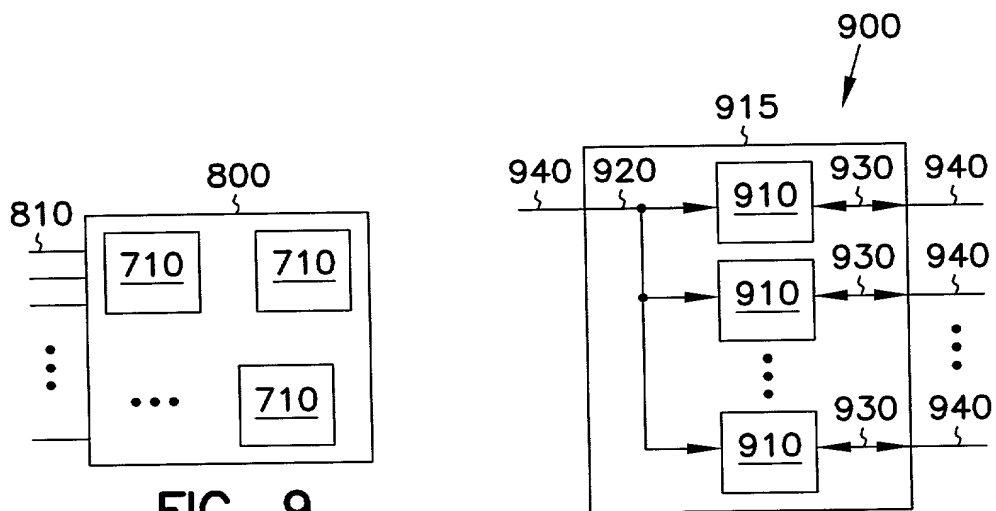


FIG. 9

FIG. 10

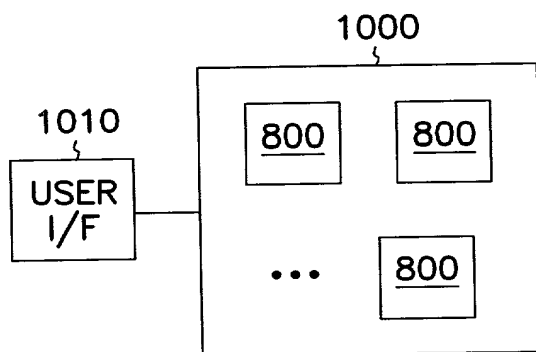
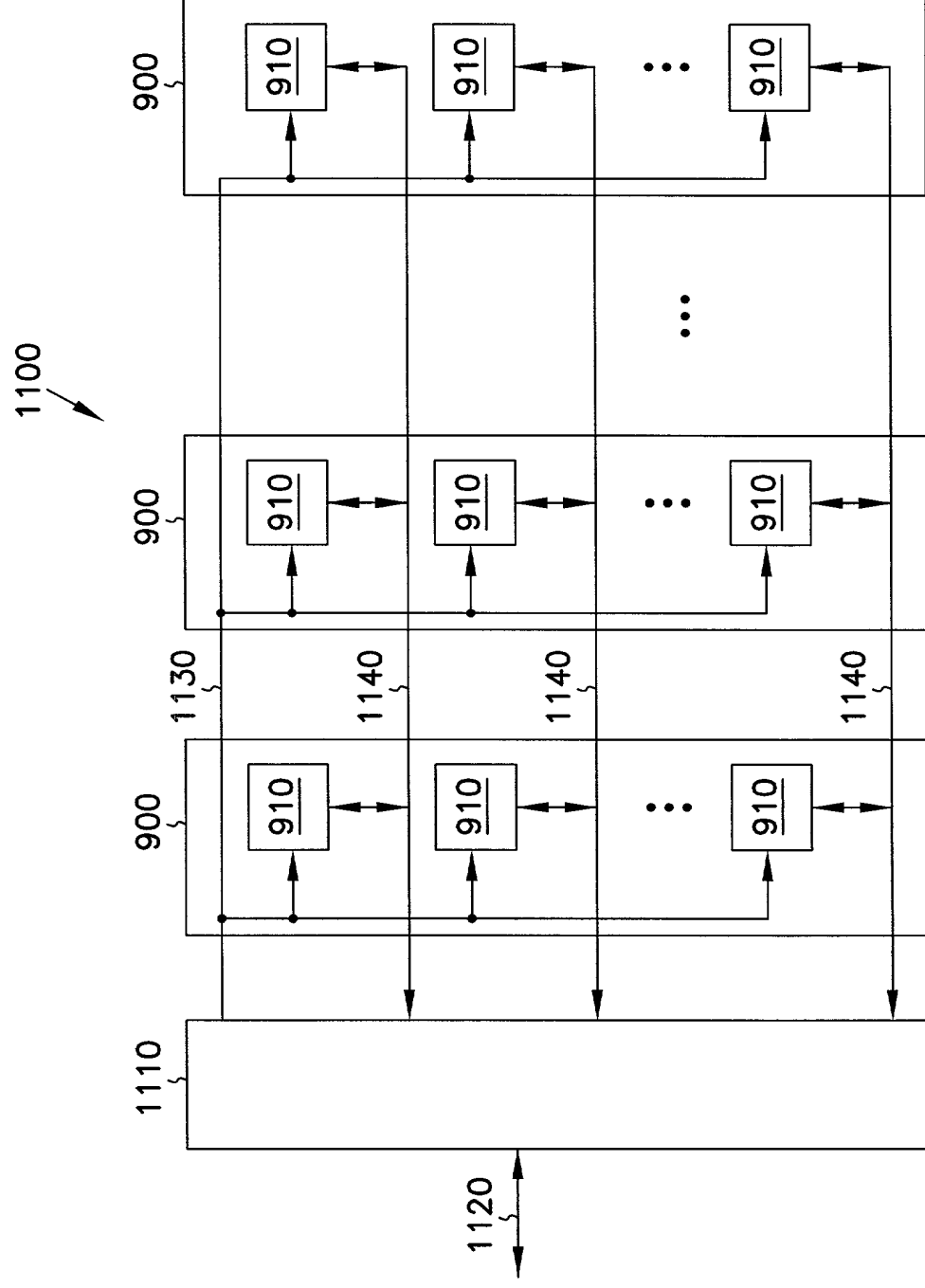


FIG. 11



**FIG. 12**



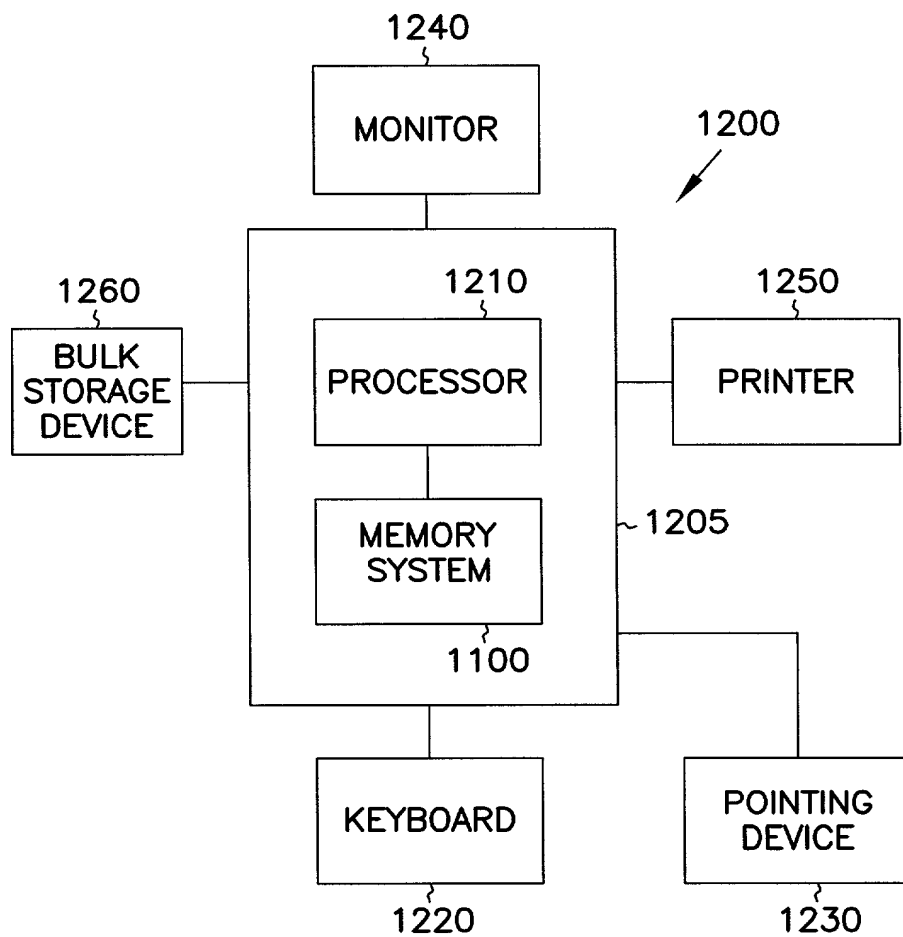


FIG. 13

**DECLARATION FOR PATENT APPLICATION**

As a below named inventor I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**SELECTIVE DEPOSITION OF SOLDER BALL CONTACTS .**

The specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56 (see page 3 attached hereto).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on the basis of which priority is claimed:

**No such claim for priority is being made at this time.**

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below.

**No such claim for priority is being made at this time.**

I hereby claim the benefit under Title 35, United States Code, § 120/365 of any United States and PCT international application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which became available between the filing date of the prior application and the national or PCT international filing date of this application.

**No such claim for priority is being made at this time.**

656T30 1.3656

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full Name of sole inventor : **Paul A. Farrar**Citizenship: **United States of America**Residence: **So. Burlington, VT**

Post Office Address: 17 Yandow Drive

So. Burlington, VT 05403

Signature: Paul A. Farrar

Paul A. Farrar

Date: 2/16/99

Full Name of inventor:

Citizenship:

Residence:

Post Office Address:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Full Name of inventor:

Citizenship:

Residence:

Post Office Address:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Full Name of inventor:

Citizenship:

Residence:

Post Office Address:

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

§ 1.56 Duty to disclose information material to patentability.

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is canceled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is canceled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§ 1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

- (1) prior art cited in search reports of a foreign patent office in a counterpart application, and
- (2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

- (1) it establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or
- (2) it refutes, or is inconsistent with, a position the applicant takes in:
  - (i) opposing an argument of unpatentability relied on by the Office, or
  - (ii) asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

- (1) Each inventor named in the application;
- (2) Each attorney or agent who prepares or prosecutes the application; and
- (3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.

**S/N Unknown****PATENT****IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Applicant: Paul A. Farrar

Examiner: Unknown

Serial No.: Unknown

Group Art Unit: Unknown

Filed: Herewith

Docket: 303.572US1

Title: SELECTIVE DEPOSITION OF SOLDER BALL CONTACTS

**POWER OF ATTORNEY BY ASSIGNEE AND  
CERTIFICATE BY ASSIGNEE UNDER 37 CFR § 3.73(b)**Assistant Commissioner for Patents  
Washington, D.C. 20231

Sir:

Micron Technology, Inc., assignee of the entire right, title and interest in the above-identified application by assignment attached hereto, hereby appoints the attorneys and agents of the firm of SCHWEGMAN, LUNDBERG, WOESSNER & KLUTH, P.A., listed as follows:

Adams, Matthew W.	Reg. No. P-43,459	Fordenbacher, Paul J.	Reg. No. 42,546	Lundberg, Steven W.	Reg. No. 30,568
Agustin, J. Michael	Reg. No. 24,916	Forrest, Bradley A.	Reg. No. 30,837	Mates, Robert E.	Reg. No. 35,271
Azora, Suneel	Reg. No. 42,267	Harris, Robert J.	Reg. No. 37,346	McCrackin, Ann M.	Reg. No. 42,858
Bianchi, Timothy E.	Reg. No. 39,610	Holloway, Sheryl S.	Reg. No. 37,850	Padys, Danny J.	Reg. No. 35,635
Billion, Richard E.	Reg. No. 32,836	Huebsch, Joseph C.	Reg. No. 42,673	Polglaze, Daniel J.	Reg. No. 39,801
Black, David W.	Reg. No. 42,331	Kalis, Janal M.	Reg. No. 37,650	Schwegman, Micheal L.	Reg. No. 25,816
Brennan, Thomas F.	Reg. No. 35,075	Klima-Silberg, Catherine I.	Reg. No. 40,052	Sieffert, Kent J.	Reg. No. 41,312
Brooks, Edward J., III	Reg. No. 40,925	Kluth, Daniel J.	Reg. No. 32,146	Slifer, Russell D.	Reg. No. 39,838
Clark, Barbara J.	Reg. No. 38,107	Lacy, Rodney L.	Reg. No. 41,136	Steffey, Charles E.	Reg. No. 25,179
Drake, Eduardo E.	Reg. No. 40,594	Leffert, Thomas W.	Reg. No. 40,697	Terry, Kathleen R.	Reg. No. 31,884
Dryja, Michael A.	Reg. No. 39,662	Lemaire, Charles A.	Reg. No. 36,198	Viksnins, Ann S.	Reg. No. 37,748
Embretson, Janet E.	Reg. No. 39,665	Litman, Mark A.	Reg. No. 26,390	Woessner, Warren D.	Reg. No. 30,440
Fogg, David N.	Reg. No. 35,138				

and also attorneys Michael L. Lynch (Reg. No. 30,871) and Lia M. Pappas (Reg. No. 34,095) of Micron Technology, Inc., as its attorneys with full power of substitution to prosecute this application and to transact all business in the Patent and Trademark Office in connection therewith.

The assignee certifies that the above identified assignment has been reviewed and to the best of the assignee's knowledge and belief, title is in the assignee.

Please direct all correspondence regarding this application to the following:

Schwegman, Lundberg, Woessner & Kluth, P.A.  
Attn: Thomas W. Leffert  
P.O. Box 2938  
Minneapolis, MN 55402

Telephone: (612) 371-2103  
Facsimile: (612) 339-3061

Dated: 2-18-99

MICRON TECHNOLOGY, INC.

By: Name: Michael L. LynchTitle: Chief Patent Counsel